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12a. DISTRIBUTION / AVAILABILITY STATEMENT
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12 b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The project, which was scheduled to terminate in November 2001, was extended to January 2003, to allow more possibility for technology transfer. The last Report covered the period from the beginning of the project through December 2001. It provided documentation of: all papers written to that date (46), number of personnel supported (36), number of degrees awarded (12 Ph.D. and 10 Masters), and the various awards and recognitions received by the team. It gave concise summaries of 15 example research results that deal with a wide range of basic research from innovative mathematical modeling to the extraction of complex buildings, road grids, and cars, to effective visualization. The most significant accomplishment is the fact that the team of members from diverse research areas functioned as an integrated entity that resulted in accelerated progress. This report gives information subsequent to the last report including papers, degrees, and particularly technology transfer.

14. SUBJECT TERMS	15. NUMBER IF PAGES
Bayesian reasoning; linear features; invariance; triangulation; sensor modeling; terrain extraction; hyperspectral data analysis; building and road grid extraction	
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Enclosure 1

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18
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Introduction

This Muri Research Center began in September 1996 and was scheduled to terminate in November, 2001. The completion date was extended to January 19, 2003. Since the primary objective of the extended period was to allow more possibility for technology transfer, the sixth interim progress report dated March 2002, documented the activities cumulatively through December 31, 2001.

The Center is composed of three participating organizations, each providing expertise which is complementary to the others. This Final Report, therefore, covers the additional papers, degrees, and in particular technology transfer during the period since then.

Purdue University, from which two areas of expertise are provided:

> *Photogrammetry and Geospatial Image Analysis* under professors Edward M. Mikhail, who is the Center's Director, and James S. Bethel, Geomatics Engineering (GE), School of Civil Engineering (CE).
>
> *Multispectral and Hyperspectral Remote Sensing* under Professor David A. Landgrebe, School of Electrical and Computer Engineering (ECE).

University of Southern California providing:

> *Image Understanding* expertise under Professor Ram Nevatia, Director of the Institute for Robotics and Intelligent Systems

BAE SYSTEMS Mission Solutions, (Formerly: Marconi Systems, Inc. which was formerly GDE Systems, Inc.) providing:

> *3D Extraction, Visualization, and Technology Transfer* under chief engineer Joseph R. Spann

1. LIST OF PAPERS

During the MURI Project, the research team produced a total of 51 papers. These are divided into categories: 8 manuscripts submitted but not yet published; 7papers published in peer-reviewed journals; and 36 published in non-peer-reviewed journals or in conference proceedings. These manuscripts can be accessed in full at the following web site: http://www.ecn.purdue.edu/MURI/ under the link "publications". The following are those written since the previous most comprehensive progress report.

a. MANUSCRIPTS SUBMITTED BUT NOT YET PUBLISHED

Purdue Civil Engineering – Geomatics Engineering Area

1- Elaksher A., J. Bethel, and E. Mikhail, 2003. *Roof Boundary Extraction Using Multiple Images*, The Photogrammetirc Record, accepted, to appear March 2003.

2- Elaksher A., J. Bethel, and E. Mikhail, *Building Extraction from Multiple Images*, submitted to PE&RS.

c. PAPERS PUBLISHED IN NON-PEER-REVIEWED JOURNALS OR IN CONFERENCE PROCEEDINGS

Purdue Civil Engineering – Geomatics Engineering Area

1- Elaksher A., and J. Bethel, 2002. *Reconstructing 3D Buildings from LIDAR Data*, The 3rd International Workshop on Mapping Geo-Surficial Processing Using Laser Altimetry, Columbus, OH, October, 2002.

2- Elaksher A., J. Bethel, and E. Mikhail, 2002. *Reconstructing 3D Building Wireframes from Multiple Images*, ISPRS Commission III, Symposium 2002, Graz, Austria, September, 2002.

3- Elaksher A., and J. Bethel, 2002. *Reconstructing 3D Buildings from LIDAR Data*, ISPRS Commission III, Symposium 2002, Graz, Austria, September, 2002.

2. SCIENTIFIC PERSONNEL

A total of 36 persons were supported during the life of the research project: 5 professors; 10 professional/scientific staff; and 21 graduate students.

a. Purdue Civil Engineering – Geomatics Engineering Area

1-Edward M. Mikhail, Principal Investigator
2-James S. Bethel, Associate Professor
3-Henry Theiss, Graduate Research Assistant/Visiting Assistant Professor
4-John Marshall, Graduate Assistant
5-Changno Lee, Graduate Research Assistant/Post-Doctoral Research Associate
6-Ibrahim Aly, Graduate Research Assistant
7-Pakorn Apaphant, Graduate Research Assistant
8-Kwon Kim, Graduate Research Assistant
9-Constantine Msemakweli, Graduate Research Assistant
10-Ahmed Elaksher, Graduate Research Assistant
11-John Tosh, Graduate Research Assistant
12-Todd Johanesen, Graduate Research Assistant

b. Purdue Electrical and Computer Engineering

1-David Landgrebe, Professor

2-Saldju Tadjudin, Graduate Research Assistant

3-Varun Madhok, Graduate Research Assistant

4-Qiong Jackson, Graduate Research Assistant

5-Bor-chen Kuo, Graduate Research Assistant

6-Murat Dundar, Graduate Research Assistant

7-Larry Biehl, Research Engineer

c. University of Southern California

1-Ram Nevatia, Professor

2-Keith Price, Research Professor

3-Andres Huertas, Research Scientist

4-Tao Zhao, Graduate Research Assistant

5-Sung Chun Lee, Graduate Research Assistant

6-Zu Whan Kim, Graduate Research Assistant

7-Sanjay Noronha, Graduate Research Assistant

8-Jian Li, Graduate Research Assistant

9-Christohe Vestri, Graduate Research Assistant

d. BAE Systems Mission Solutions Inc.

1-Joseph Spann, Project Management

2-Mark Vriesenga, Early Project Manager

3-James Olson, Research Scientist

4-Fidel Paderes, Research Scientist

5-Bingcai Zang, Research Scientist

6-Karen Kaufman, Research Scientist

7-Lou Oddo, Research Scientist

8-Jeffrey Schmidt, Research Scientist

3. INVENTIONS

None

4. DEGREES AWARDED

A total of 23 degrees were awarded: 13 PhDs and 10 Masters. The additional degree since the last comprehensive report is:

a. Purdue Civil Engineering – Geomatics Engineering Area

1-PhD to Ahmed Elaksher, August 2002, "Building Extraction from Multiple Images".

5. HONORS/AWARDS/RECOGNITION

Complete list is in the comprehensive report

6. SCIENTIFIC ACCOMPLISHMENTS

Listed in the comprehensive report

7. TECHNOLOGY TRANSFER

The following six software systems were transferred to the U.S. Army Topographic Engineering Center, Fort Belvoir, VA.

1. The **Building Extraction System** is divided into two groups: 2D Roof Extraction in Image Space and 3D Reconstruction of the building. A tutorial was also attached with the programs to help in understanding the procedures. A Manual explaining the details of each step was also submitted to assist in running the system.

2. **Sensor Model 1 (Airborne Pushbroom : HYDICE)**

   This program estimates sensor parameters (6 Exterior Orientation Parameters for each scan line + Focal length) using control data (points and lines) and calculates the Root Mean Square Error for check data. It employs the following:

   a. Platform Model: 1st Order Gauss-Markov Process
   b. Linear Feature Model: Coplanarity Equation

3. **Sensor Model 2 (Airborne Whiskbroom: HyMap)**

   This program estimates sensor parameters (6 Exterior Orientation Parameters for each scan line + Focal length) using control data (points and lines) and computes the Root Mean Square Error for check data. It makes use of the following:

   a. Platform Model: 1st Order Gauss-Markov Process
   b. Linear Feature Model: Coplanarity Equation

4. **Sensor Model 3 (Airborne Whiskbroom: HyMap)**

   Same as Sensor Model 2 except that:

   a. It uses only control points
   b. It uses the orientation data (6 EO) supplied by the vendor
   c. It estimates differences between supporting data from vendor and the 6 EO calculated by low order (less than 3) polynomial

5. **Sensor Model 4 (Invariance supported Photogrammetry)**

   This program estimates frame camera orientation parameters (5 IO + 6 EO for each camera) without any prior information about interior orientation of camera. It is based on the concept of a three camera system. All the image points for control data should be measured in all three images. The program involves two steps. First (Image transfer), relative orientation is established among the three cameras. Next (Object reconstruction), absolute orientation is performed between 3D model space and ground space.

6. **Orthorectification of airborne pushbroom or whiskbroom images**

   Produces an ortho-rectified image using estimated sensor parameters and a digital elevation model, or DEM.